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AN EXTERNAL ELECTRONIC FEEDBACK SYSTEM APPLIED TO A CRYOGENIC MICRO-CALORIMETER

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ABSTRACT

In order to improve the maximum counting rate of cryogenic μ-calorimeters used as particle detectors, the application of an External Electronic Feedback system (EEF) is under development in Genoa.

A description of the experimental setup of such a system and a model which describes the properties of the EEF applied to a current biased μ-calorimeter is reported. The model shows the maximum performance obtainable with such a system, which in principle allows one to improve the detector speed by some order of magnitude. The model includes also a theoretical noise analysis and the calculation of the intrinsic energy resolution obtainable using this kind of system, showing that the EEF does not worsen the energy resolution.

The theoretical calculations have been compared with the experimental results obtained in Genoa. The comparison shows a good agreement between theoretical predictions and experimental results.

INTRODUCTION

Using a bolometer as a particle detector at very low temperatures the length of the pulse is a limitation to these detectors. The activity of the source must be usually restricted to less than a few Bequerel as higher activities introduce non-negligible pileup[1],[2]. In the experiments requiring high statistics this will result in a very long measuring time.

The use of an Electrothermal Feedback Transition Edge Sensor (ETF-TES) can considerably reduce this problem[3]; in the ETF-TES a superconducting film is *voltage biased* and the current through it is measured with a SQUID; this possibility is very attractive, but it is limited to a particular kind of sensor and to a particular working condition.

By using the same philosophy the application of a similar system to *current biased* sensors is under development in several laboratories, and in particular in Genoa[4]. This method consists of an External Electronic Feedback system (EEF), which reduces the power dissipated in the bolometer after each energy release with external hardware electronics.

In order to show the potential of such a system and its characteristics, a model which describes a current biased μ-calorimeter working in the EEF condition has been developed. The goal of this model is to show what are the possible performance of the EEF and its limits. From the practical point of view the model can show what is the relation between EEF parameters and the detector speed.

An extension of the theoretical noise analysis of a μ-calorimeter to the case of EEF is taken into account in the model as well; this analysis shows that the intrinsic energy resolution of a μ-calorimeter working in this condition is not influenced by the EEF. The EEF system can be then applied to μ-calorimeters, with the goal of increasing the detector counting rate, without worsening the detector energy resolution which is the most important characteristic of this type of detector.

In the analysis the classical notation which is generally used for feedback systems has been applied to the bolometer theory. This has been found to be an helpful notation for future calculations.

The theoretical calculations have also been compared with the experimental results obtained in Genoa using an EEF system with a μ-calorimeter composed of a Neutron Transmutation Doped (NTD) germanium thermistor and a superconducting rhenium polycrystalline foil as absorber[(4)]. In this case it has been possible to reduce the pulse length from more than 150 ms to less than 5-10 ms, gaining a factor of 30 in the maximum detector counting rate.

EXPERIMENTAL APPARATUS

The EEF consists of an electronic feedback system applied to the bolometer which reduce the power dissipated in the bolometer after each energy release. The feedback idea uses the fact that the current which passes throw the sensor heats the bolometer. When there is an energy release in the absorber, in general a long time is needed before the temperature of the bolometer goes down. If after an event the power dissipated in the bolometer is decreased the temperature decreases much faster. This can be done in two ways, which are shown in figure 1 and which I call system of type 1 and system of type 2.

In the system of type 1 an extra power generator is fixed to the μ-calorimeter, and the EEF regulates this extra power; in the system of type 2 the EEF regulates directly the power dissipated in the bolometer by the current bias. This second method is simpler to realize because it does not require a change in the bolometer setup, but at the same time it is limited by the fact that the feedback response time must be slower with respect to the thermalization process, otherwise the changes in the current bias can influence the thermalization process changing the bolometer working point.

The input of the EEF is the output signal of the bolometer; this is filtered for the feedback stability, then reduced in order to have a signal generally smaller than some mV and then subtracted from the DC bias voltage of the extra power generator in the system of type 1 or from the DC bias voltage of the sensor in the system of type 2. All of the feedback electronic apparatus can be composed of low noise amplifiers which add a negligible noise contribution to the input bias voltage.

In my theoretical model I will consider EEF system of type 1; the EEF system of type 2 is a particular case in which the current bias, the load resistance and the resistance of the power generator have to be replaced by those of the sensor.

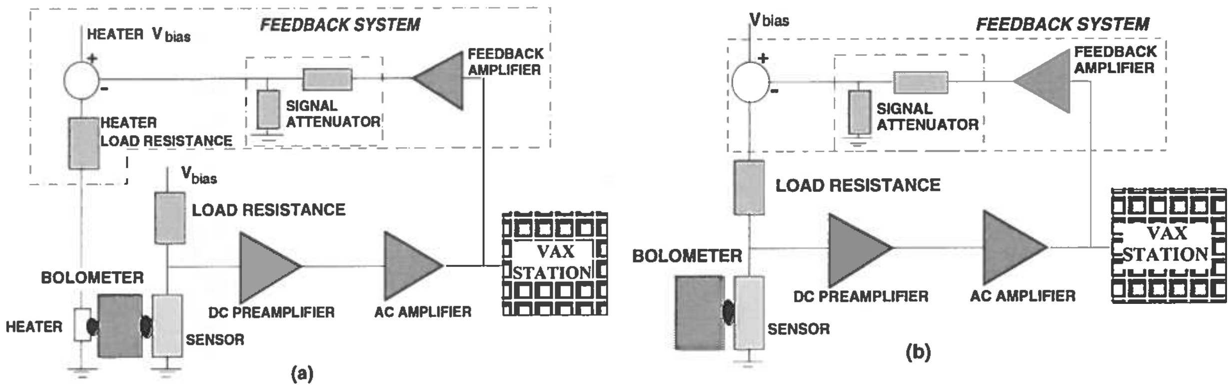


Figure 1 – Experimental setup of the EEF using an external heater (a) and regulating the sensor current bias directly (b).

THE BOLOMETER MODEL

In order to understand the EEF model I want to introduce first the model for bolometers as particle detectors. The theory of bolometer operation has been treated by many authors[5-9]; in particular a simple theoretical description I'm referring to here is that of Maul and Strandberg of 1969[5]. These theories have been extended to the non-equilibrium case with a noise analysis by Mather in 1982[10] and 1984[11]. The extension of these theories to cryogenic particle detectors has subsequently been realized by Moseley, Mather and McCammon in 1984[12]. More complicated and more detailed descriptions will be also considered at the end of this paragraph[13].

I report here the bolometer analysis made by Moseley et al.[12], but with the notation which is generally used in feedback systems; this notation will be very helpful later on in this paper. A cryogenic thermal detector is composed of an absorber, where the electromagnetic or recoil energy is converted into phonons, and a sensor for detecting them. Absorber and sensor are connected by a strong thermal link; the bolometer has a weak thermal link with the refrigerator. The sensor is a resistor in which the electrical resistance strongly depends on temperature. The characteristic parameter of a sensor is the parameter α which is defined by:

$$\alpha = \frac{1}{R}\frac{dR}{dT} \tag{1}$$

where R is the electrical resistance at a temperature T.

The equation that determines the thermal response of the bolometer to an incident heat input dQ is given by[5]:

$$C\frac{dT}{dt} + G(T - T_0) = i^2 R + W(t) + \Delta(vi) \tag{2}$$

where C is the heat capacity of the bolometer, T is the temperature of the bolometer, G is the thermal conductance between the bolometer and the refrigerator, T_0 is the refrigerator base temperature, i is the current through the bolometer, R is the electrical resistance of the sensor, $W(t)$ is the power dissipated in the bolometer due to the energy release and v is the voltage across the bolometer element. The bolometer intrinsic time constant is given by $\tau = C/G$.

After each energy release the bolometer temperature increases, then the resistance of the sensor changes (it increases for transition edge thermometers and it decreases for semiconductor thermistors); this effect changes the power dissipated in the bolometer and it is known as electrothermal feedback. The electrothermal feedback can be positive or negative and it can be taken into account introducing the parameters $G_P = \ldots$ $R_L + R$ ($P = i^2R$ = power dissipated in the bolometer, R_L = load resistance) and $G_{eq}=G+G_P$ in the eq. 1 and 2. A schematic representation of the bolometer in the frequency domain is reported in figure 2; in this representation the effect of the electrothermal feedback is evident. Considering the expression for the closed loop transfer function of a feedback system[14], the bolometer temperature deviation with respect to the equilibrium temperature (ΔT), considering that the bolometer is constant current biased is then:

$$C\frac{d(\Delta T)}{dt} + G_{eq}\Delta T = W(t) \tag{3}$$

In the frequency domain it is possible to write

$$\Delta T(\omega) = \frac{1}{G_{eq}} \cdot \frac{1}{1 + j\omega\tau_{eq}} W(\omega) \tag{4}$$

where $\tau_{eq}=C/G_{eq}$.

If $W(t)=E\delta(t)$ the solution of eq. 3 is:

$$\Delta T = \frac{E}{C} \cdot \exp(-t/\tau_{eq}) \tag{5}$$

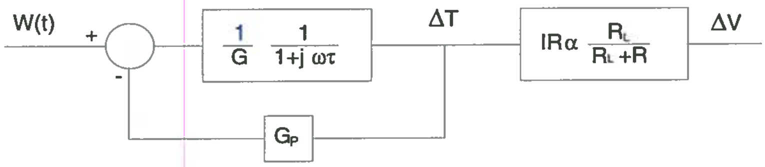


Figure 2 – Schematic representation of a current biased μ-calorimeter.

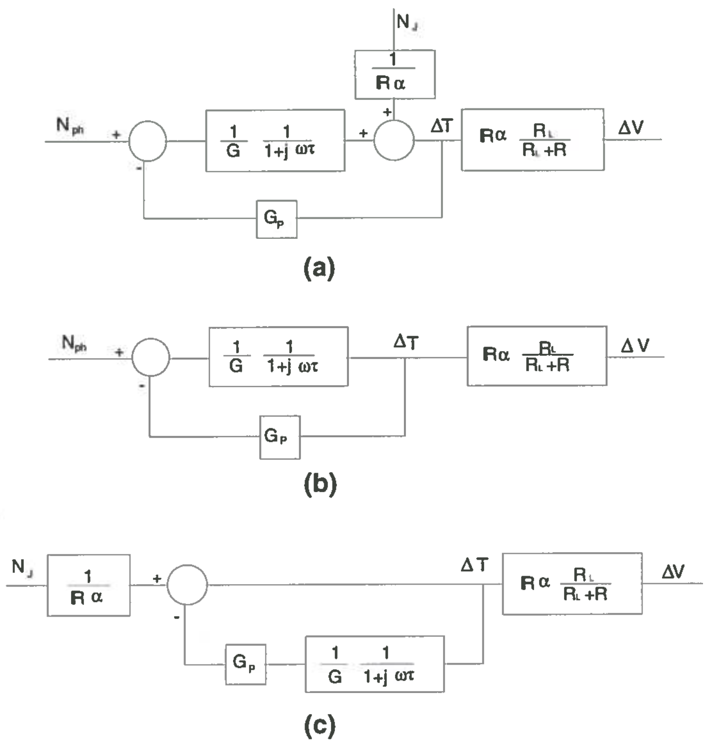


Figure 3 – Influence of phonon and Johnson noise in a current biased m-calorimeter (a) and equivalent circuits for the NEP calculation (b)(c).

For the noise calculation, neglecting the noise of the read-out electronics, the only important contributions are the phonon noise contribution and the Johnson noise contribution. The intrinsic contributions independently. The NEP practically corresponds to the ratio between the voltage variation at the sensor edges due to the noise and the voltage variation at the sensor edges due to the unitary δ-like pulse. The intrinsic energy resolution is given by the formula:

$$\Delta E_{RMS} = \left(\int_0^{\infty} \frac{4}{NEP(f)^2} df \right)^{-1/2} \tag{6}$$

where f is the frequency.

The influence of the two noise contributions is reported in figure 3; fig. 3a shows the same schematic of fig. 2 with the two noise contributions (N_{ph} and N_J) in evidence; fig. 3b and fig. 3c show the schematic for both contributions independently indicating the noise source as input and the voltage at the sensor edges as output. Without developing all the steps which can be found in [10] and [12] the input values of N_{ph} and N_J in fig. 3 can be written as:

$$N_{ph} = \sqrt{4k_b G T^2} \left(\frac{\int_{T_0}^{T} \frac{(T\, k(T\,))^2}{(Tk(T))^2} dT}{\int_{T_0}^{T} \frac{k(T\,)}{k(T)} dT} \right)^{1/2} \tag{7}$$

$$N_J = \sqrt{4k_b TR} \tag{8}$$

where k_b is the Boltzmann constant and $k(T)$ is the function describing the temperature dependence of the thermal conductivity of the heat link material. Different expressions for the phonon noise contribution can be found in the literature[15] and can be taken into account in the value of N_{ph}, but this does not influence the following considerations.

Solving the schematic representation of fig. 3 the NEP of the Johnson and phonon noise contributions have to be added in quadrature and are given by:

$$(NEP)_J^2 = 4k_b T \frac{G^2}{P\alpha^2}(1+\omega^2\tau^2) \tag{9}$$

$$(NEP)_{ph} = 4k_b G T^2 \frac{\int_{T_0}^{T} \frac{(T\, k(T\,))^2}{(Tk(T))^2} dT}{\int_{T_0}^{T} \frac{k(T\,)}{k(T)} dT} \tag{10}$$

Using the assumptions that $k=k(T_o)t^{\beta}$ and $C=C(T_o)t^{\gamma}$, where $t=T/T_o$, it is possible to integrate the equation 6, giving

$$\Delta E_{RMS} = \xi \sqrt{k_b T^2 C} \tag{11}$$

with

$$\xi = 2 \cdot \left(\frac{(\beta-1)t^2}{A\left(1-t^{-(\beta+1)}\right)} \right)^{1/2} \cdot \left(\frac{1}{A^2} + \frac{1-t^{-(2\beta+3)}}{2\beta+3} \right)^{1/4} \tag{12}$$

where $A=T \cdot \alpha$.

A more complete theoretical analysis of a cryogenic particle detector has been realized in the 1995 by Pröbst et al.[13]. In this analysis all the possible thermal contributions to the detector have been taken into account, in particular the different contributions of thermal and non thermal-phonons (thermalization process), the difference in the time constants between the electrons in the thermometer and the phonons in the absorber, and a finite thermal conductance along the thermometer. The final expression for the bolometer equation is rather complicated, but in the frequency domain it is possible to consider the bolometer equation as the product of several terms of the form of the eq. 5 with different time constants τ_I:

$$\Delta T(\omega) = W(\omega)\prod_i \frac{A_i}{1+j\omega\tau_i} \qquad (13)$$

where the product is made over all the possible contributions to the bolometer response. I have written the equation of a cryogenic particle detector in the form of eq. 13 in order to generalize my feedback analysis to all the possible bolometer models, which can be always be written in the form of eq. 13.

THE BOLOMETER MODEL IN THE EXTERNAL FEEDBACK CONFIGURATION

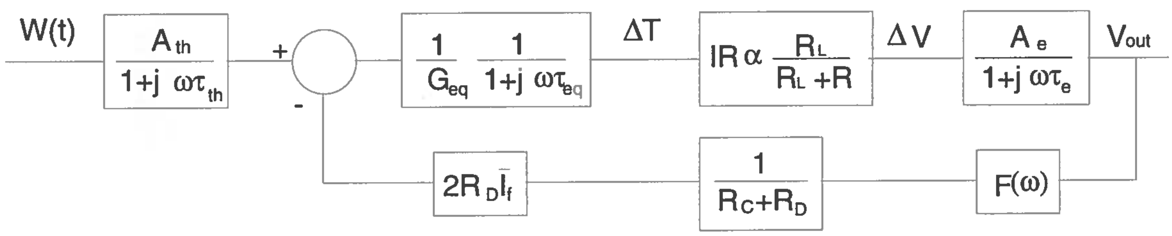


Figure 4 – Schematic representation of a current biased μ-calorimeter with external feedback.

I will start my consideration with a simplified bolometer model; after that I will extend my consideration to the more complicated and more realistic case of eq. 13. In my model I'm using the hypothesis that the energy release is of the form $W(t)=E\delta(t)$, and that the phonons are exponentially thermalized with a decay time faster than the bolometer time[13]. A schematic of the system in the frequency domain is shown in figure 4.The energy release $E\delta(t)$ is thermalized with a time constant τ_{th} and it is then converted into a temperature variation ΔT by the bolometer. The bolometer amplification and time constant are $A_b=1/G_{eq}$ and $\tau_{eq}=C/G_{eq}$ respectively. The temperature variation ΔT is then converted into a voltage variation ΔV by the thermometer; the conversion is given by the relation $\Delta V=I\ R\ \alpha\ \Delta T$. This voltage is then read out by an electronic system with amplification A_e and time constant $\tau_e<<\tau_{eq}$. For the feedback system this voltage output is filtered by the feedback apparatus $F(\omega)$ and then converted into heat using a resistance R_C in order to convert the voltage into a current I_f, and a power dissipater R_D; $\bar{I}_f$ is the mean current trough R_D when there are no pulses. The feedback loop is then closed on the bolometer.

The first step of this theoretical analysis is to find the form of F(ω) in order to have a stable feedback system with the required time constant τ_f; in the next paragraph I will analyze the noise under these conditions. A first hypothesis which is generally verified is that the time constant of the electronics is sufficiently low with respect to the required time constant of the feedback, $\tau_e<<\tau_f$; in this case in my analysis I can consider the electronic amplifier simply by a transfer function $H_e(\omega)=A_e=const.$ In this case the open loop transfer function[14][16][17] which I must take into account for the feedback stability and the time constant calculation is:

$$H_{open-loop}(\omega) = F(\omega)\cdot\frac{IR\alpha}{G_{eq}}\cdot\frac{2R_D\overline{I_f}A_e}{R_C+R_D}\cdot\frac{R_L}{R_L+R}\cdot\frac{1}{1+j\omega\tau_{eq}} \tag{14}$$

For the feedback stability and the time constant calculation I use the Bode criteria[14]. For the feedback stability the condition is:

$$\frac{dH_{open-loop}(\omega)}{d\omega} = -10\,dB/decade \tag{15}$$

when $|H_{open-loop}(\omega)|=1$.

The time constant of the feedback is given by

$$\tau_f = 1/\omega_f \tag{16}$$

where ω_f is the frequency at which $|H_{open-loop}(\omega_f)|=1$.

For the feedback stability the simpler choice in my model is $F(\omega)=F=const$; obviously nothing changes choosing $F(\omega)$ with a time constant lower than τ_f. In this condition the relation which allows one to calculate the time constant of the feedback is:

$$\left|1+j\omega_f\tau_{eq}\right| = F\cdot\frac{IR\alpha}{G_{eq}}\cdot\frac{2R_D\overline{I_f}A_e}{R_C+R_D}\cdot\frac{R_L}{R_L+R} \tag{17}$$

which corresponds to:

$$F = \frac{G_{eq}}{IR\alpha}\cdot\frac{R_C+R_D}{2R_D\overline{I_f}A_e}\cdot\frac{R_L+R}{R_L}\cdot\left(\frac{\tau_{eq}}{\tau_f}-1\right) \tag{18}$$

In the hypothesis that $\tau_{eq}>>\tau_f$ this reduces to:

$$F = \frac{G_{eq}}{IR\alpha}\cdot\frac{R_C+R_D}{2R_D\overline{I_f}A_e}\cdot\frac{R_L+R}{R_L}\cdot\frac{\tau_{eq}}{\tau_f} \tag{19}$$

In this case the temperature variation due to an energetic release of the form $W(t)=E\delta(t)$ is given by

$$\Delta T = \frac{E}{C}\cdot\frac{\tau_f}{\tau_{eq}}\cdot\exp(-t/\tau_f) \tag{20}$$

This means that the maximum temperature variation is reduced by a factor τ_f/τ_{eq}. This fact can be very helpful when too high a temperature variation could introduce non-linearity in the energy calibration[18].

I can assume now that the bolometer has two time constants (τ_1 and τ_2), or, in order to have an higher feedback accuracy, that the feedback electronics has been chosen with a time constant greater then the required feedback time constant: $F(\omega)=F/(1+j\omega\tau_2)$ where $\tau_2>\tau_f$. In this case for the feedback stability a phase lead component must be introduced in the feedback loop. A phase lead is simply a system with transfer function $H_{phase-lead}=(1+j\omega\tau_1)/(1+j\omega\tau_2)$ where $\tau_1<\tau_f<\tau_2$; this system allows one to have the correct value of the open loop transfer function first derivative for the stability. The use of a phase lead component has to be taken into consideration in the feedback system project, but does not influence my theoretical considerations about the EEF.

In this case eq. 17 must be written as

$$\left|(1+j\omega_f\tau_1)(1+j\omega\tau_2)\right| = F\cdot IR\alpha\cdot\frac{R_L}{R_L+R}\cdot A_1A_2\cdot\frac{2R_D\overline{I_f}A_e}{R_C+R_D} \qquad (21)$$

where A_1 and A_2 are the amplification terms ($A_i = 1/G_{eq}$). In the hypothesis that $\tau_1, \tau_2 >> \tau_f$ this gives:

$$F = \frac{1}{IR\alpha}\cdot\frac{R_L+R}{R_L}\cdot\frac{R_C+R_D}{2R_D\overline{I_f}A_e}\cdot\frac{1}{A_1A_2}\cdot\frac{\tau_1\tau_2}{\tau_f^2} \qquad (22)$$

As it is possible to note that the structure is similar to that of eq. 19, I can then extend these considerations to the case of several time constants reported in eq. 13, with the product of terms of the form $A_i/(1+j\omega\tau_i)$ which can be due to the feedback control or to the bolometer time constant. I can then neglect all the terms with this form which have a time constant smaller than the required feedback time constant, while all the other terms give a contribution of the form of eq. 19. The difference between this case and the case of eq. 19 concerns the feedback stability; a sufficient number of phase lead modules for the feedback stability has to be used in the feedback project.

Using the same notation used in eq. 13 the eq. 22 can be then generalized as:

$$F = \frac{1}{IR\alpha}\cdot\frac{R_L+R}{R_L}\cdot\frac{R_C+R_D}{2R_D\overline{I_f}A_e}\cdot\prod_i\frac{\tau_i}{A_i\tau_f}\cdot\prod_j\frac{1}{A_j} \qquad (23)$$

where the product over i is made taking into consideration all the terms which have a time constant $\tau_i > \tau_f$, while the product over j is made taking into consideration all the terms which have a time constant $\tau_j < \tau_f$.

From simple considerations it is also possible to see that the improvements in the detector speed are limited by the thermalization time constant, which is in any case generally at least a few orders of magnitude smaller than the bolometer time constant. I have then two different possible operation conditions, depending on the fact that the feedback time constant is lower or higher than the thermalization time. In the first case the detector is a constant temperature detector and the information about the energy release is obtained by measuring the power variation applied by the feedback system for the temperature stability (the pulse tail is determined by the thermalization time constant); while in the second case the detector employment is the same than without feedback, but with shorter pulse decreasing time (determined by the feedback time constant).

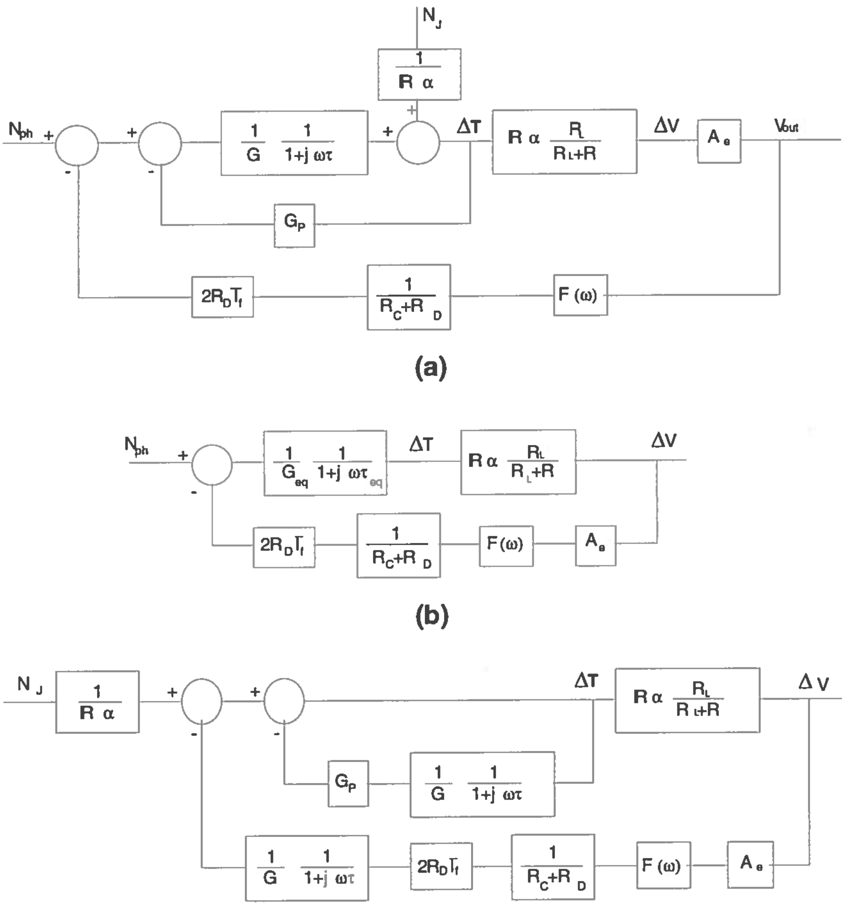
Considering what has been pointed out previously about the possible way to realize the feedback, an immediate conclusion is that it is possible to use a feedback system of type 2 only in the second working condition, in order to not influence the sensor working point during the thermalization process.

NOISE EVALUATION AND INTRINSIC ENERGY RESOLUTION

For the noise evaluation I want to extend the calculations reported before to the case of the external feedback condition; it is possible eventually to extend the obtained results to different and more complicate expressions like[9][15][19].

The schematic of a μ-calorimeter working in the external feedback condition, taking into consideration the Johnson noise and the phonon noise is illustrated in fig. 5a. For simplicity I'm referring to the case of eq. 18, with *F(ω)=F=constant*.

Considering that the expressions for N_J and N_{ph} are the same as reported in eq. 7 and 8, I'm interested in calculating the influence of the feedback system on the intrinsic energy resolution ΔE_{RMS}. I'm repeating here the same steps I did before, using the same notation. In this case the two noise contributions to the voltage variation at the sensor edges are reported in fig. 5b and 5c.



(c)

Figure 5 – Influence of phonon and Johnson noise in a current biased μ-calorimeter with external feedback (a) and equivalent circuits for the NEP calculation (b)(c).

The calculation now is more complicated, but developing all the steps the obtained expression for the *NEP* of both contribution are:

$$(NEP)_J^2 = 4k_bT\frac{G^2}{P\alpha^2}(1+\omega^2\tau^2) \qquad (24)$$

$$(NEP)_{ph} = 4k_bGT^2\frac{\int_{T_0}^{T}\frac{(T\,k(T))^2}{(Tk(T))^2}dT}{\int_{T_0}^{T}\frac{k(T)}{k(T)}dT} \qquad (25)$$

Notice that both the contributions are the same as those for the case without feedback Therefore in this case the intrinsic energy resolution is too given by equation 11 and 12.

Up to now I have neglected the noise contribution of the first amplifier in the read-out electronics chain, which is correct in almost all of the cases. This term does not influence the intrinsic energy resolution, but in the real case can limit the experimental energy resolution. I want to repeat here the considerations reported for the Johnson and phonon noise. Supposing that the signal of the μ-calorimeter is read out using a low noise preamplifier with Gain 1, time constant negligible with respect to the time constant of the system and white noise with density N_e, the Noise Equivalent Power due to this contribution is equal to:

$$NEP_{electronics} = N_e \tag{26}$$

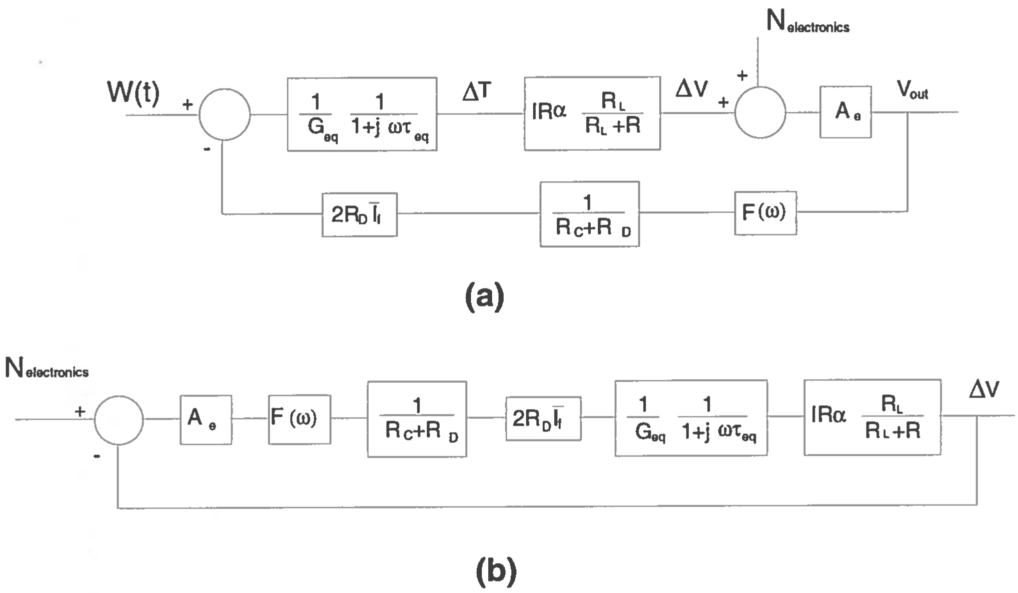


Figure 6 – Influence of the noise of the first amplifier in the read out electronics (a) and equivalent circuit for the NEP calculation (b).

Introducing the EEF model, and repeating the same procedures used for the Johnson noise, as reported in figure 6, it is possible to see that the contribution of the noise of the first amplifier is reduced by the external feedback system, and that the $NEP_{electronics}$ is the same with and without EEF.

From this theoretical calculation I can then conclude that the EEF does not worsen the energy resolution of a μ-calorimeter used as a particle detector.

COMPARISON WITH EXPERIMENTS

In order to verify the validity of the conclusion reported in this paper, the theoretical calculations have been compared with the experimental work which is under development in Genoa[4]. I used a bolometer composed of a superconducting rhenium polycrystalline foil as absorber and an NTD germanium thermistor as sensor. An external ^{55}Fe X-ray source (5890 eV and 6540 eV X-rays) was used for the reference signal. The bolometer temperature was varied between 90 mK and 120 mK.

The μ-calorimeter has been used both in the normal condition and with an EEF system of type 2.

The comparison of both result is shown in figure 7, where a pulse due to the detection of a 5898 eV X-ray is displayed. In fig. 7a the bolometer was working under normal conditions, while in fig. 7b the EEF has been introduced. In agreement with the theoretical prediction of [13] the system has two different time constants:

$$\tau_1 = (4.8 \pm 0.2)ms$$

$$\tau_2 = (22.0 \pm 0.5)ms$$

For this reason, in agreement with the consideration reported before, a phase-lead module has been used for the feedback stability.

Varying the EEF parameters in agreement with equation 23, it has been possible to reduce the pulse decay time to 0.7 ms, which means a gain of a factor 30 in the pulse length. The pulse height using the external feedback was reduced by a factor of 30 in agreement within one σ with the theoretical prediction, and the base-line noise was 16 eV of σ at 5890 eV with and without EEF.

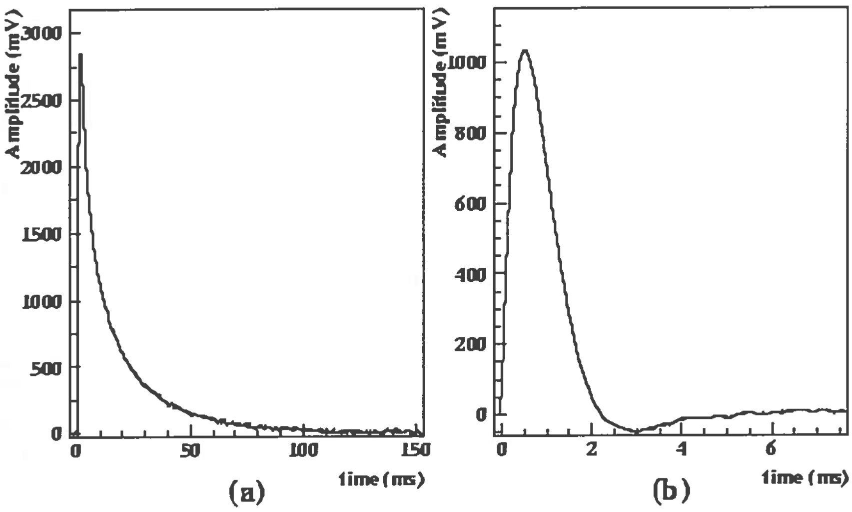


Figure 7 – Pulse shape without (a) and with (b) EEF.

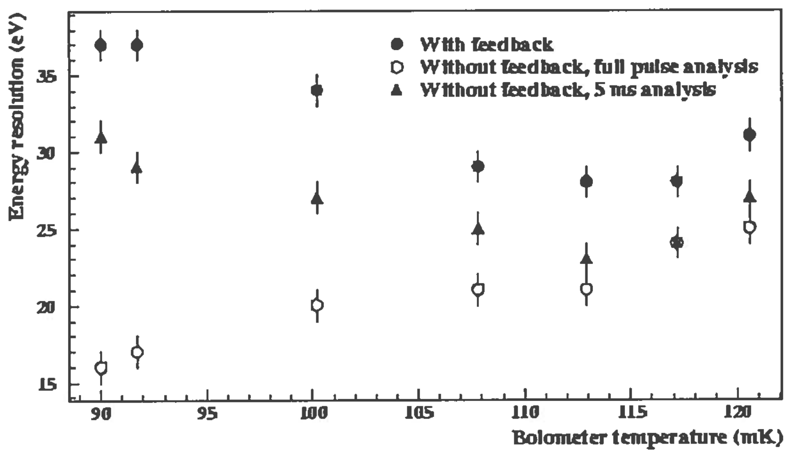


Figure 8 – Detector energy resolution σ versus detector temperature with EEF (black circles), without EEF (white circles) and without EEF taking into account only the first 5ms of the pulses (triangles).

This preliminary result confirms the results of the theoretical calculation and demonstrates the possibility of using the EEF for improving the speed of a μ-calorimeter used as a particle detector, but it is not yet satisfactory because of the energy resolution worsening. In agreement with the baseline noise the energy resolution of the μ-calorimeter without the EEF was 16 eV of σ at 5890 eV; the corresponding energy resolution of the μ-calorimeter with the EEF was σ=37 eV. Varying the temperature of the bolometer it has been possible to improve the energy resolution of the μ-calorimeter with the feedback system obtaining the best energy resolution σ=28 eV, a factor 1.75 worse than without the EEF (see figure 8).

The question at this point is to understand the origin of the energy resolution degradation. I can exclude the influence of the baseline noise which is the same with and without EEF. Using the sampling theorem I can also exclude the influence of a changing in the sampling rate for the digital analysis (the sampling rate with feedback is 20 times faster than without feedback). The two possible explanations are that either the energy distortion is introduced directly by the EEF or that it is from the loss of information on the pulse tail. If the worsening of the energy resolution is due to the loss of information on the pulse tail it is possible to see the same effect considering the data without external feedback, without taking into consideration in the analysis the pulse tail. I analyzed therefore the data without external feedback taking into consideration only the first 5 ms of the pulses. I found that the dependence of the energy resolution versus the temperature of the bolometer has the same shape as in the case of the external feedback system (see figure 8). I can then conclude that the EEF does not introduce directly an indetermination on the pulse energy, but that this depends on the loss of information on the pulse tail and it is a specific characteristic of the used bolometer.

Why a loss of information on the pulse tail worsens the energy resolution is still under investigation but probably depends on a long thermalization time in the superconducting rhenium absorber.

CONCLUSIONS

In order to improve the maximum detector counting rate of a cryogenic μ-calorimeter the application of an external electronic feedback system is under development in Genoa. A model describing the properties of a current biased μ-calorimeter working in this condition has been reported. This model shows that it is possible to use such a system in order to improve the detector speed without worsening the energy resolution. The analysis shows that the intrinsic maximum counting rate obtainable using an external feedback system is limited only by the thermalization time.

This model allows one to choose in a simple way the feedback parameters depending on the bolometer characteristics and on the desired detector speed.

The comparison of the theoretical analysis with the experimental results obtained in Genoa with a rhenium bolometer shows good agreement between theoretical predictions and experimental data (the pulse length has been reduced by a factor of 30), but the energy resolution with the feedback system is 1.7 times worse than without the feedback system. I checked that this loss in the energy resolution does not directly depend on the introduction of the feedback system, but on the loss of information on the pulse tail and it is probably directly related to the μ-calorimeter characteristics. A detailed study of the thermalization processes in superconductors is now required in order to understand for which reason this occurs.

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